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Interaural bimodal pitch matching with two-formant vowels

François Guérit[1], Josef Chalupper[2], Sébastien Santurette[1], Iris Arweiler[2], Torsten Dau[1]

[1]*Centre for Applied Hearing Research, Technical University of Denmark*
[2]*Advanced Bionics GmBH*

Introduction

For bimodal patients, with a hearing aid (HA) in one ear and a cochlear implant (CI) in the opposite ear, usually a default frequency-to-electrode map is used in the CI. This assumes that the human brain can adapt to interaural place-pitch mismatches. This "one-size-fits-all" method might be partly responsible for the large variability of individual bimodal benefit. Therefore, knowledge about the location of the electrode array is an important prerequisite for optimum fitting. Theoretically, the electrode location can be determined from CT-scans. However, these are often not available in audiological practice. Behavioral pitch matching between the two ears has also been suggested, but has been shown to be tedious and unreliable (Carlyon et al., 2010). Here, an alternative method using two-formant vowels was developed and tested.

Hypothesis

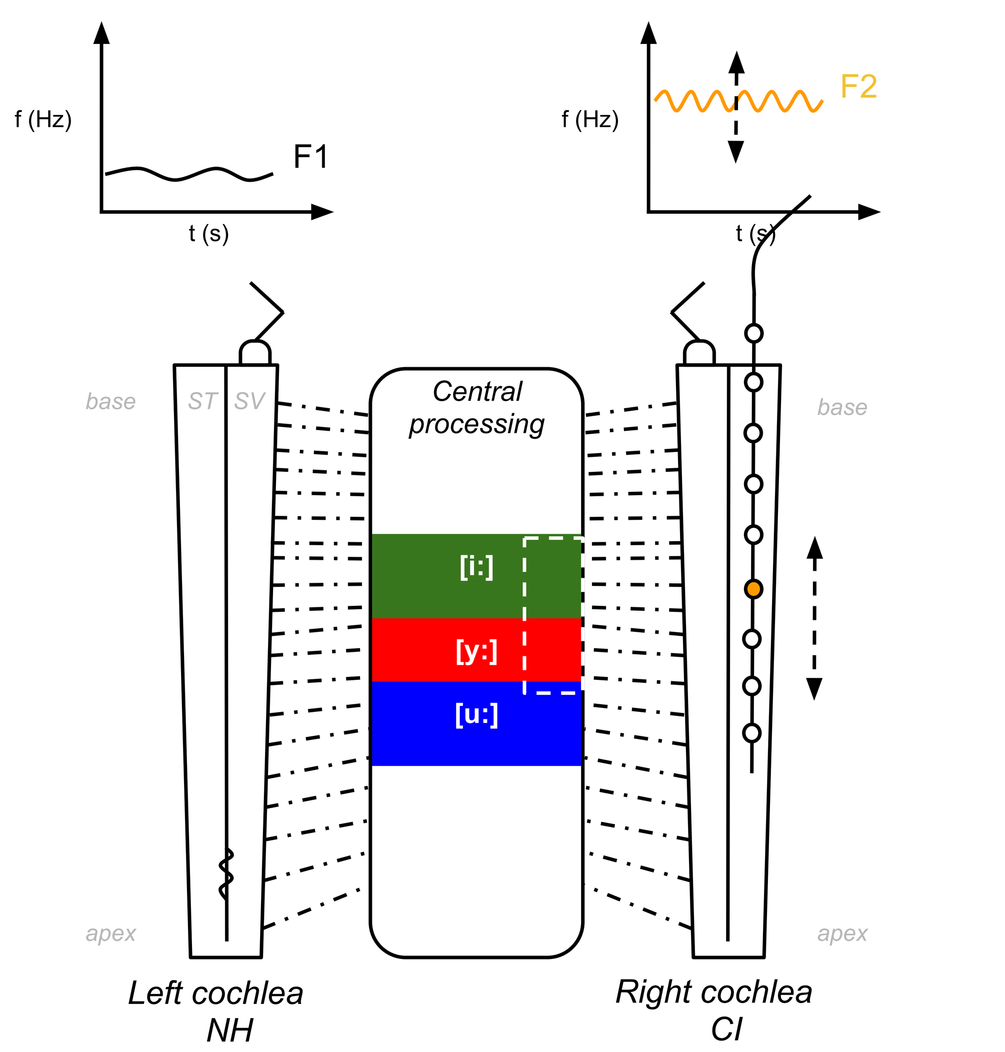

Fig.1 If the implant is perfectly fitted, the three vowels of this example should be perceived identically when presenting the second formant (F2, yellow) in either the NH or CI side. However, if there is a shift towards the base, the perceived vowel map obtained by varying F2 (*dashed white rectangle*) should also show a shift.

Methods

Stimuli Two-formants vowels were produced using Matlab-based Klatt synthesizer (Klatt, 1980) and mixed with consonants to form a /t/-/vowel/-/k/ stimulus. Noise-vocoder (Litvak et al., 2007) was simulating in the right ear a perfect fit and two different mismatches.

Procedure Subjects had to categorize (forced choice) the perceived stimuli into different vowel propositions using a Matlab GUI.

Subjects All subjects were native German speakers. Tests with normal hearing (NH) subjects were done in Denmark, tests with bimodal subjects were achieved in the ENT department of the UnfallKrankenHaus, Berlin.

NH without vocoder

Frequence of "TÜK" reponse [%], dichotic presentation

F1 [Hz] \ F2 [Hz]	800	1000	1200	1400	1600	1800	2000
250	3	15	63	68	78	8	0
400	0	0	0	0	0	0	0
600	0	0	0	0	0	0	0
750	0	0	0	0	0	0	0

Settings:
- F1 presented on the left ear
- F2 presented either on the left or right ear
- 10 repetitions per stimulus
- 4 NH subjects
- Possible choices: TUK, TÜK, TIK, TOK, TÖK, TEK, TAK, TÄK

Results:
- similar results when having F2 in the left or right ear
- if F1 is fixed at 250 Hz, TUK, TÜK and TIK are successively perceived by increasing F2
- if F1 is fixed at 400 Hz, TOK, TÖK and TEK are successively perceived by increasing F2

Fig.2 Distribution of the "TÜK" category for all subjects, scaled from 0% (white) to 100% (bright red)

NH with vocoder

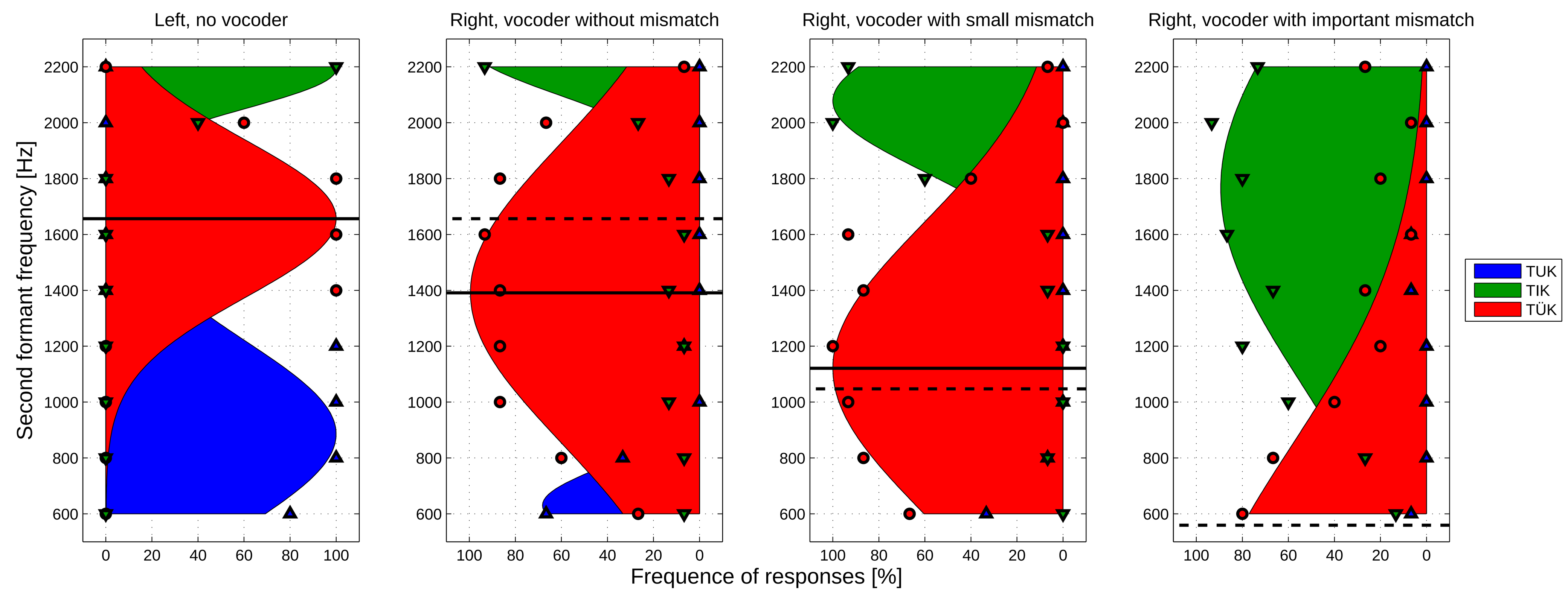

Fig.3 Distribution of vowel categories for subject "NH4" when changing F2, with F1 fixed at 250 Hz in the left ear. (A): F2 presented in the left ear. (B), (C) and (D): vocoded F2 presented in the right ear. Areas show a fitted gaussian curve of vowel distribution (markers). To help the eye, center frequency of the fitted "TÜK" (solid black line) and its expected frequency from the vocoder settings (dashed line) are shown.

Settings:
- F1=250 and 400 Hz, F2 presented either on the left or vocoded on the right ear
- 5 repetitions (F2 on the left ear)/ 15 repetitions (F2 on the right ear) per stimulus
- 8 NH subjects
- Possible choices: TUK, TÜK, TIK, TOK, TÖK, TEK
- vocoder training with audiobook

Results:
- Fusion of percepts across ears was difficult but possible after audiobook training
- individual vowel maps are affected by simulated mismatches
- variability is high between subjects, especially when simulating the big mismatch

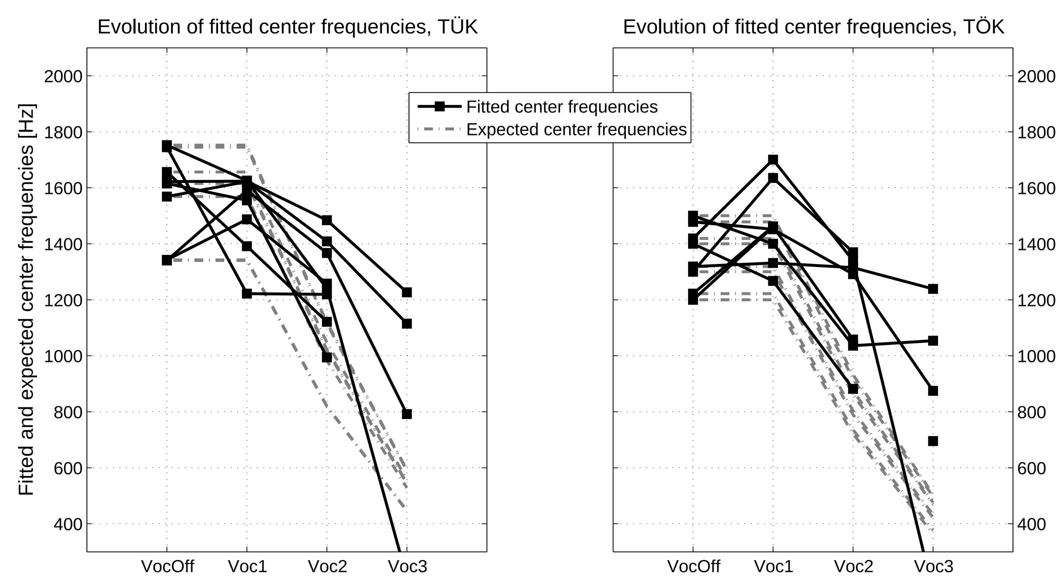

Fig. 4 Eight subjects fitted center frequencies (dark) for the vowel TÜK (left) and TÖK (right). Expected center frequencies are shown in dashed gray lines.

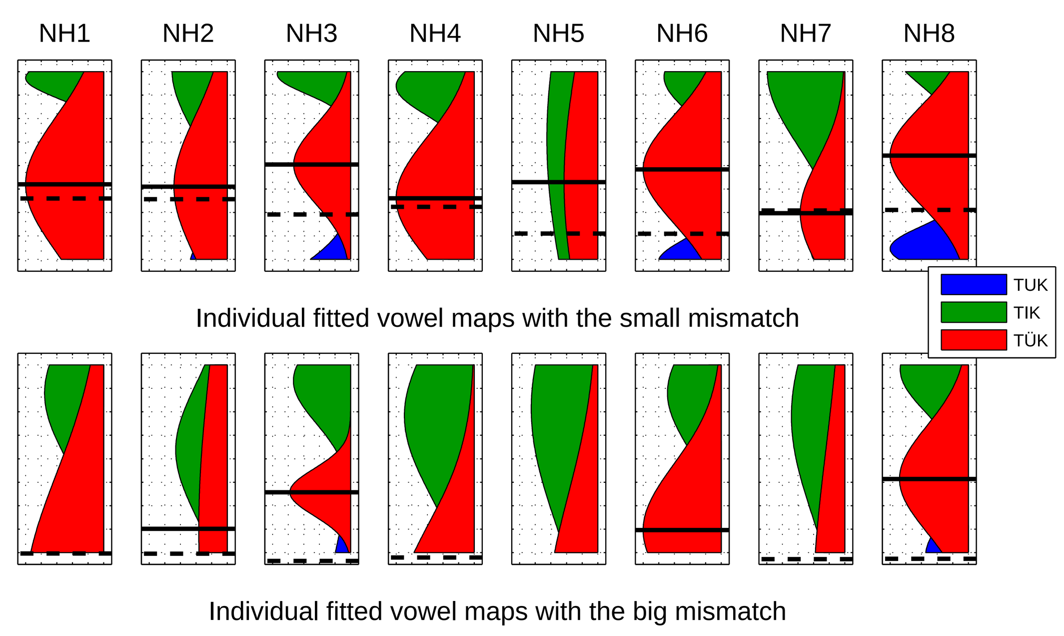

Fig. 5 Eight subjects fitted vowel distributions, with vocoder settings 2 (top) and 3 (bottom), simulating respectively a small and big mismatch. F1=250 Hz.

Bimodal patients

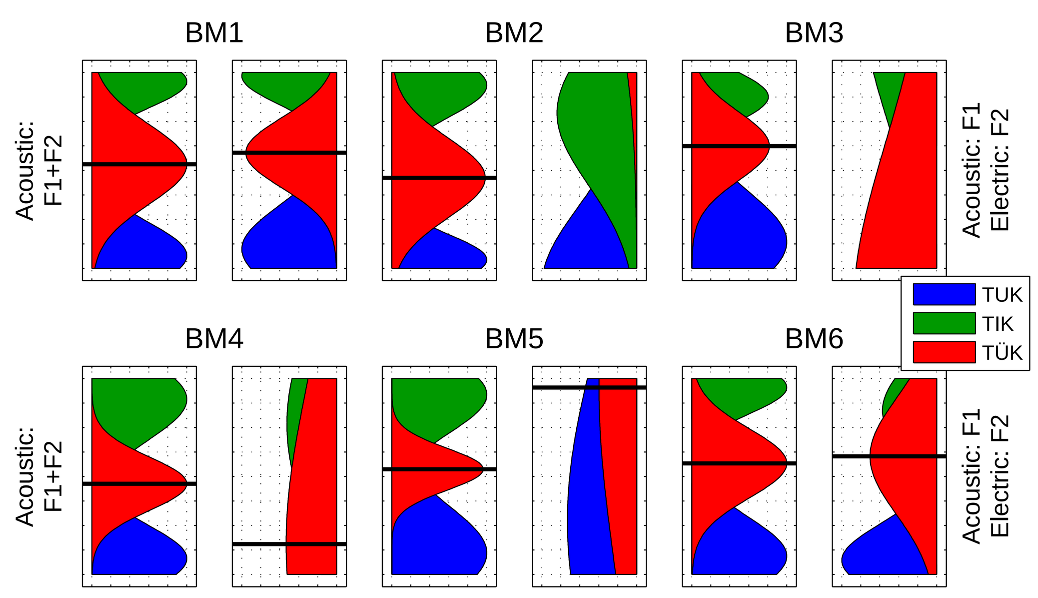

Fig. 6 Six bimodal patients vowel distributions, when F2 was presented acoustically (left of each subject panel) and electrically (right).

F1=250 Hz only was presented (choices reduced to TUK, TÜK, TEK), with 10 repetitions. There is an important variability, future CT-scans comparison might help interpreting the results.

Discussion

- small shift simulation with a vocoder(≈ 500 Hz) can be estimated by looking at the distribution of three-vowels groups

- bigger shift (≈ 800 Hz) creates an important variability, probably due to range limitations and difficulty to fuse percepts

- variability in bimodal patients is likely to come from nonsensory biases arising from the very different percepts in the two ears, as shown in (Carlyon et al., 2010)

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